Lattice Imaging with Sub Ångstrom Information

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By installing a new generation of high resolution electron microscope (HREM), NCEM enables scientists to investigate materials with short bond lengths at a mono atomic level. Diamond is the most challenging of these materials in this respect. For the first time mono atomic resolution was achieved in different projections of the diamond lattice by exploitation of the sub angstrom information limit of a field emission electron microscope.

Background - There is a growing need to understand physical processes at a mono atomic level in order to design artificially structured nano-crystals for applications that may involve e.g. hard coatings or microelectronics. In addition, hard materials often contain light elements such as oxygen, nitrogen or carbon that are difficult to detect because of their small electron scattering power.

Figure 1 reviews bond lengths of ceramics and semiconductors. It is seen that typical values range from 1.5 through 2.8Å. A carbon-carbon distance of 1.5Å is the shortest value. Any projection of the diamond lattice along a low index zone axis for lattice imaging reduces the C-C distance even further. Consequently, a resolution around 1Å is required to separate atomic columns in diamond. Similar arguments apply for the other ceramic-like, or wide band gap materials with bond lengths smaller than 2Å and for metallic compounds.

A point resolution of 1.8Å is rather typical for modern high resolution microscopes. Defects in many semiconductor materials can be studied in detail by HREM with this resolution. However, this level of resolution is not sufficient to determine the local atomic structure of materials with shorter bond lengths which, therefore, commonly remain uncertain. A microscope with a resolution of around one Ångstrom will change this picture dramatically.

Accomplishment - In a collaboration with industry and visitors from the University of Dundee, UK, NCEM scientists demonstrated that the information limit of a Philips CM300 FEG/UT microscope can be exploited to access information from the sub Ångstrom region. CVD grown diamond films were chosen for this study because of the exceptional short C-C bond length that prohibited HREM studies of defects and interfaces in the material. In addition, an identification of the diamond lattice spacings along a [110] zone axis gives evidence for the transfer of information between 2.06Å (111-reflection) and 0.89Å ((004)-reflection). Figure 2 (left) shows a lattice image of the CVD diamond taken along the [110] zone axis. It is seen that a dumbbell structure could be resolved. It is the first time that such an image could be recorded. The observation implies that (004) reflections were transmitted or dynamically excited. The (004) reflections are visible in the Fourier transform of the image (center). A comparison of an averaged image with a simulation (right) supports the interpretation that the (004) reflections at 0.89Å were in fact contributing to the image.

In conclusion it was demonstrated that the sub Ångstrom information limit of a field emission microscope can be exploited to access structural information on this length scale. As a result it is now feasible to investigate materials with short bond lengths such as ceramics at a mono atomic level.

Figure 1: Interatomic distances and energy gap of ceramics and semiconductors. A modern microscope can typically resolve monoatomic columns with interatomic distances located in the right hand side of the diagram. It takes a resolution of around 1Å to achieve single atom resolution in diamond and the other materials with short bond length (left hand side of the diagram).

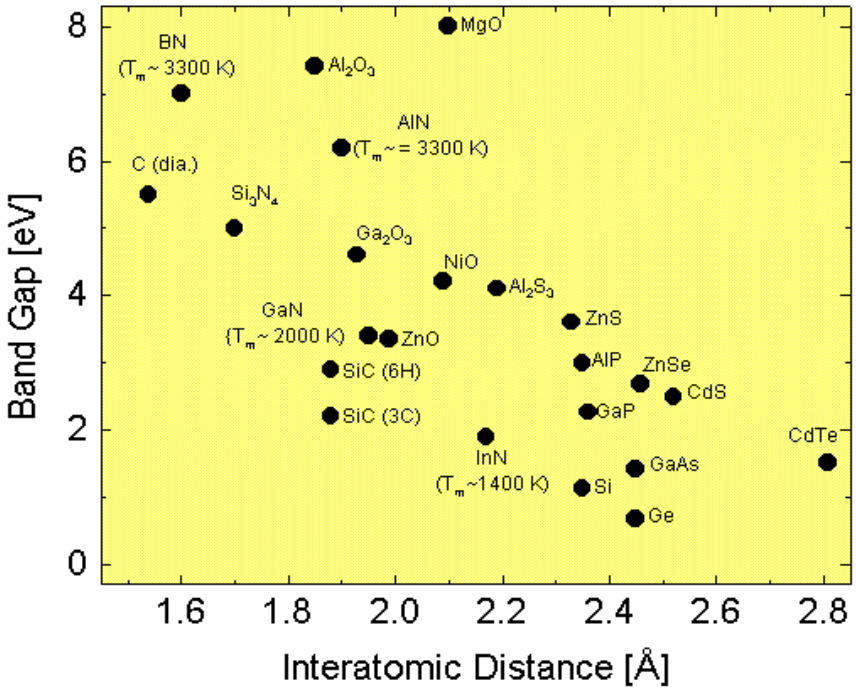

Figure 2: Resolution of dumbbells in diamond. Left: [110] lattice image as recorded in the microscope. Center: Fourier transform of the marked area shows 0.89Å spacings out to the (400) reflection. Right: comparison of the averaged image with a simulation. Simulation parameters are listed.